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On-Site and Off-Site Long-Term Economic Impacts of Soil Fertility Management Practices

The Case of Maize-Based Cropping Systems in Kenya

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ABSTRACT

This article analyzes the on-site and off-site economic impacts of various sustainable land management (SLM) practices in Kenya. Long-term trial data are used to establish the relationship between SLM practices and maize yield. The analysis of on-site effects focuses on the profitability of maize production at the farm level, while the examined off-site effects include carbon sequestration and siltation from maize farms, which increase the cost of potable water production. The major contribution of this study is the use of long-term experimental data to estimate the impacts of land management practices on crop yield and consider their off-site benefits and costs.

The results of this study show that soil and water conservation (SWC) structures reinforced with leguminous plants are more profitable when the plants are used as fodder, as opposed to situations in which only SWC structures are used. SWC structures reinforced with vegetation had lower maintenance costs, whereas those that were not reinforced with leguminous trees were not profitable over the long-term period. These results suggest that complementary and multipurpose SWC practices are more likely to be adopted compared to non-complementary and/or single-purpose practices. Thus, SWC practices should be promoted as a package of complementary technologies. If it is not feasible to promote a mix of complementary enterprises, high value crops are likely to make SLM practices more profitable. In areas where SLM practices are not profitable, promotion of alternative livelihoods is necessary. Adoption of SLM also provides global environmental services worth 10% of the net present value of the SLM practices over the 50-year period addressed in the present study Finally, the results of this analysis suggest that farmers who offer significant environmental services should be compensated for their efforts.

Keywords: agroforestry, land degradation, soil erosion, Sub-Saharan Africa, sustainable land management Kenya

1. INTRODUCTION

Land degradation is the loss of productivity and capacity of land to provide ecological and socio-economic goods and services (Johnson et al., 1997; Smyth and Dumanski, 1995). In sub-Saharan Africa (SSA), land degradation is a serious problem threatening poor people who depend on agriculture for their livelihoods. This issue also poses a challenge to economic development, since the economies of most countries in the region are based on agriculture. Dregne (1990) observed that land degradation in 13 African countries contributed to a 20% decrease in agricultural productivity, while other studies have indicated that the reductions of agricultural GDP due to land degradation range from less than 1% to as high as 55% (Ruben et al., 2007; Bojö, 1996; Enters, 1997). These findings underscore the importance of land conservation for supporting the agriculture-based economies in Africa. In addition to its on-site effects (e.g. reduction of soil fertility), land degradation also leads to off-site effects such as sedimentation of surface water bodies, runoff and flooding (FAO, 2007; Pagiola, 1999; Scherr and Yadav, 1996; Schroeder, 1993; Unruh et al., 1993) at both the local and national levels. On the global scale, land degradation has been identified as one of the factors contributing to climate change and loss of biodiversity (FAO, 2007). Land degradation contributes to climate change primarily through the emission of greenhouse gases as a result of bush and crop residue burning and other processes that lead to disruption of the carbon cycle. For example, conventional tillage disturbs soils, accelerating soil erosion and the decomposition of organic carbon (Hussain et al., 1999). Degraded land also loses vegetative covers capable of absorbing short wave radiation, further contributing to global warming (Gisladottir and Stocking, 2005). Changes in vegetative cover can also change the albedo (reflectivity) of the land, altering the energy absorption (Schelling, 2007); this may have positive or negative effects on warming, depending on the albedo of the surface that replaces the vegetation.

Soil erosion and nutrient depletion are the major forms of land degradation in SSA (Pieri, 1989; Oldeman, 1994; Oldeman et al., 1991; Voortman et al., 2000). In addition to contributing to decreases in agricultural productivity and the consequent food and nutrition insecurity, soil nutrient depletion and erosion may also contribute to deforestation and losses of biodiversity by forcing farmers to abandon nutrient-starved soils and cultivate more marginal areas such as hillsides and rainforests. Such a situation has been seen in densely populated areas of Kenya, where encroachment on protected forests is a common problem (Hitimana et al., 2004). Furthermore, land degradation-induced decreases in biodiversity and water quality could contribute to increases in pests and diseases (Scherr, 2000).

Given the known and potential on- and off-site negative impacts of land degradation, governments in SSA and their development partners have recently begun designing strategies and policies to address land degradation as part of their poverty reduction and environmental conservation efforts. This study is accordingly conducted for the purpose of determining the on- and off-site economic impacts of land degradation in central Kenya.

2. ACCOUNTING FOR OFF-SITE EFFECTS OF LAND DEGRADATION

Many types of land degradation have off-site effects (see review by de Graaf, 1996; Pagiola, 1999; Puigdefabregas, 1998). Herein, we will focus on soil erosion and vegetation degradation in crop plots, which are the major forms of land degradation in SSA with direct on- and off-site impacts (Davidson et al., 2003; Pimentel, 2006). Soil nutrient depletion is another major aspect of land degradation in Africa; although it does not have direct downstream impacts, farmers with soil nutrient-depleted plots may be forced to cultivate on fragile areas, triggering soil erosion. This suggests that soil nutrient depletion has indirect downstream effects. However, for the sake of brevity, we herein focus on soil erosion and loss of vegetation, which have direct downstream effects. Our analysis also examines the off-site effects that we can unambiguously attribute to land degradation, and for which costs and benefits data are available. We quantify the off-site impacts related to sedimentation and how it affects the cost of potable water production. We also analyze the amount of biomass in the planted trees, shrubs and grasses, and the soil carbon that is either saved by soil and water conservation or lost due to soil erosion and other channels.

This analysis is based on a case study of the Sasumua Water Treatment Plant located in the Kinale/Kikuyu watershed. The Kinale/Kikuyu catchment lies between latitudes 36º 30' and 36º 45' E and longitudes 0º 45'S and 1º 15' S, and has an elevation ranging from 1600 to 2600 meters above sea level (m.a.s.l.). The catchment is characterized by high population density and has several major sources of land degradation, including: deforestation and consequent destruction of water catchment areas and encroachment of wetlands; soil nutrient depletion due to continuous cultivation and limited soil fertility management practices aimed at replenishing depleted nutrients; overgrazing; and cultivation on fragile steep slopes without adequate SWC measures, leading to severe soil erosion.

Kinale-Kikuyu is a source of many rivers that supply water to the lowlands and urban centers of Kenya's central provinces (e.g. Nairobi). The Kinale-Kikuyu catchment spans three districts (Kiambu, Nakuru and Nyandarua) and sustains several major cropping systems, including maize, potatoes-beans, fruits-vegetables, and coffee-bananas. The majority of farmers in the area (72%) intercrop maize with other crops, such as Irish potatoes and beans (Lekasi et al., 2005). Approximately 64.7% of area farmers use inorganic fertilizers (Ibid), a level that is far higher than rates reported in other countries of SSA (Morris et al., 2007). The main utilized fertilizer is diammonium phosphate (DAP) (used by 77.8% of farmers) followed by calcium nitrate (CAN) for topdressing (16.7%). The fertilizer application rate ranges from 1 to 200 kg of DAP per acre, with a mean of 46 kg per acre. The maize yield for farmers is about 1.5 tons/ha (De Groote et al., 2005).

In this work we consider two scenarios, namely farmer practices that use what we call Sustainable Land Management (SLM), and those that do not. The SLM practices considered in this study include:

1. Agroforestry to help control soil erosion, increase carbon stock, improve soil fertility and confer other agroforestry benefits (see Sanchez et al., 1997).
2. Application of organic and inorganic fertilizers and incorporation of crop residues.
3. SWC practices commonly used in the sloping lands of Kenya, namely the *fanya juu* (which is throwing soil uphill) and *fanya chini* (throwing soil downhill) practices of terracing, as well as mulching and agroforestry.

Although these technologies are highly interrelated, we herein separate them to emphasize their importance. The major on-site (on-farm) benefits of SLM practices include: higher and sustainable crop yields; cut-and-carry systems in which trees, shrubs, grass and leguminous vegetation are cut and fed to animals; fencing and windbreaks; and diversification of production (Pagiola et al., 2007; FAO, 2007). The off-site benefits of SLM practices include watershed and soil and flood protection, water quality, water and nutrient recycling, enhancement of soil fertility, and aesthetic, cultural and spiritual improvements (FAO, 2007). The global benefits of SLM practices are mitigation of climate change and conservation of biodiversity (Ibid). Farms with no SLM practices (the control) do not practice agroforestry, use SWC structures, or apply crop residues, animal manure or fertilizer. We ensured that all factors affecting yield were the same for the treatment and control plots, i.e. all the non-treatment biophysical characteristics (e.g. soil types, moisture, slope, etc.), agronomic practices, and maize varieties were the same on the SLM and non-SLM plots for all years included in this study.

We use two common indicators for economic returns, namely the Net Present Value (NPV) and the Internal Rate of Return (IRR), to determine whether the studied SLM practices are profitable from the social perspective. Our social Cost-Benefit Analysis (CBA) takes into account the on-site and off-site costs and benefits at the levels of the farm and the society (community, district, national, regional and global), with global benefits assessed by examining the amount of carbon sequestered by the utilized SLM practices. The social NPV is compared with the private NPV; this reflects the benefits and costs that farmers realize when they ignore the off-site effects of production, and thus examines the impact of externalities of agricultural production on profit.

For the social CBA, we consider how market failures or policy-induced distortions might distort the price signals perceived by agricultural producers, and relate this to the externalities of land degradation, which might impose costs or benefits on society.[1] Although the importance of the off-site effects of land degradation is widely recognized, most previous studies have focused on the on-site effects, largely because it is difficult to quantify and value off-site effects. Here, we quantify the off-site effects of land degradation using data obtained from the Kinale/Kikuyu watershed in the central provinces of Kenya. We assess the costs and benefits of farming with and without SLM practices over a 50-year period. This period is based on the life expectancy in Kenya [48 years in 2005 (UNICEF, 2007)], which is a good reflection of the planning horizon during which a farmer actively participates in farming and bequeaths land to his/her children. Given that inheritance is the most common method of land acquisition in Africa, our results may be seen as reflecting the long-term planning horizon of farmers with good tenure security (Kabubo-Mariara, 2007) and with plans to bequeath land after retirement. Using a discount rate of 10% (see Pagiola, 1996),[2] we compute the NPV of the costs and benefits with and without soil fertility management, agroforestry and SWC structures (the three main components of SLM considered in this study). If soil erosion is the major form of land degradation in the study area, the effects of continued erosion on agricultural productivity may be estimated using the returns to investment, which are obtained by taking the difference between the streams of discounted costs and benefits calculated with and without the adoption of soil conservation practices. This valuation technique is commonly called the 'change of productivity approach.' Although there are alternative valuation techniques, such as the 'hedonic pricing approach' and the 'replacement costs approach'(Enters, 1997). the 'change of productivity approach' is the most commonly applied and widely accepted tool (for more details on the various tools see Enters, 1997), and is used herein. The approach estimates only the discounted returns to the specific conservation measure being examined.

Due to data availability problems, a simple, flexible and less data intensive model was used to determine soil loss due to erosion, namely the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1991).[3] The RUSLE model relates soil loss from a given field to its climate, soil type, topography, and management variables as follows:

$$A = RKLSCP$$

where A is the mean annual soil loss (metric tons per hectare), R is the rainfall erosivity index, K is the soil erosivity index, L is the slope length, S is the slope steepness, C is the crop factor, and P is the conservation practice factor. The relationship between soil erosion and crop yield is complex and involves many other factors that are difficult to control for (Enters, 1997). Additionally, most soil erosion data are exaggerated since they are based on small plots and then extrapolated to larger areas such as a catchment, district, region, etc. (Gisladottir and Stocking, 2005; Koning and Smaling, 2005). However, even though

1 The price distortions relevant to this study are negligible (see Methods section).

2 Other studies report higher private discount rates (for example see Holden et al., 1998, for evidence from Ethiopia, and Pender, 1996, for evidence from south India).

3 Alternative soil erosion models have been used in SSA, such as LISEM (e.g. Hessel et al., 2005) and WEPP (Klik and Zartl, 2001). However, RUSLE has been calibrated and used by many researchers in SSA.

the RUSLE results don't account for redeposition, they provide a reasonable order of magnitude estimate for the on-site costs of erosion from highlands, which are more sources than recipients of erosion. Due to its parsimonious data requirement and simplicity, RUSLE is one of the most widely used soil erosion prediction models; it has been used in Kenya and many other SSA countries (Angima et al., 2003; Angima et al., 2002; Le Roux et al., 2005).

The quantity of soil eroded is related to the corresponding crop yield in order to determine the loss of crop productivity due to soil erosion. Since crop yield is determined by many factors, the best estimates are generally obtained under experimental conditions that control for most of these factors. Once the functional relationship between crop yield and soil erosion is determined, the value of crop yield loss due to erosion is computed and used to determine the benefits and costs of investing in soil erosion control (see below for details on how the functional relationship between soil erosion and crop yield is included in our analytical method). Likewise, the value of loss of crop productivity due to soil fertility mining is determined using data from a long-term soil fertility experiment conducted in Kabete, Kenya; the Kabete experiment is one of the longest running soil fertility experiments in Africa (Swift et al., 1994), and provides a level of data unavailable for any other site in Kenya. The value of lost crop productivity is also used to determine the benefits and costs of practicing soil fertility management technologies.

The impact of deforestation and reduction of carbon stock is estimated after determining the amount of carbon lost to various silvicultural methods, and then imputing an overall value for the quantity of carbon lost. Land degradation is often correlated with increased soil carbon dioxide emissions and a reduced ability to store carbon. However, as Pagiola (1999) notes, the links between land degradation and carbon dioxide emission are numerous, complex and difficult to quantify. Some practices (e.g. bush and crop burning) can increase carbon emissions directly, while others (e.g. conventional tillage) indirectly increase carbon dioxide emission (Hussain et al., 1999). Due to issues of data availability, we herein focus on carbon changes due to soil erosion and loss of vegetation. Soil erosion carries away Soil Organic Matter (SOM). This does not necessarily lead to increased emissions, however, because much of the carbon carried away by erosion may be deposited under conditions where it may be well preserved (e.g. in riverbeds and reservoirs). Land degradation also affects the soil carbon cycle, in that degradation-induced decreases in crop and pasture production lead to lower carbon inputs in subsequent periods. Carbon stocks also tend to be unstable on cultivated plots, because decomposition and mineralization may be accelerated by soil disturbance (Olchin et al., 2008). Due to these complex relationships, the effect of land degradation on soil carbon sequestration is difficult to quantify. Hence, we herein use coefficients generated by previous studies[4] and adapt them to the Kenyan conditions. Once carbon sequestration and emission are quantified for both the with- and without-SLM scenarios, we attach a monetary value to the (presumably) reduced emissions. Other studies (e.g. Jindal, 2006) have set a value for CO_2 emission reduction at US$ 3-4 per ton of carbon, but note that the cost may be as high as $15/ton in some countries (Ibid).

4 As far as possible, citation of the source of the coefficients will be given.

3. ANALYTICAL METHODS AND DATA

Analytical Methods

Our analysis evaluates the economic viability of a number of SLM practices, namely application of the recommended inorganic and organic fertilizers, incorporation of crop residues, the use of SWC structures, and their stabilization with Calliandra hedgerows and Napier grass. We further consider the private and social NPV and IRR of SLM practices by examining the NPV per hectare for all SLM practices, and the contribution of off-site costs and benefits to the NPV. Finally, we determine the robustness of our main results by conducting a sensitivity analysis that examines the impact of yield and input and output price changes on the major policy recommendations.

To quantify the impact of each of the SLM practices and assess the profitability of their adoption, we first specify the CBA model (profit function) and then specify the biophysical relationship between the SLM practices and agricultural productivity. Equations (1) and (2) specify the profit of adopting or not adopting the SLM practices:

Profit with SLM is given by:

$$\pi_t^c = Y_t^c(P_t - Z_t^c \pm \lambda_t^c) \tag{1}$$

where π_t^c = profit with SLM practices in year t;

Y_t^c = crop yield with SLM practices in year t;

P_t = social price of output in year t;

Z_t^c = social cost of production of one unit of Y_t^c; and

λ_t^c = off-site costs/benefits with SLM practices per unit produced in year t.

Profit without SLM is given by:

$$\pi_t^d = Y_t^d(P_t - Z_t^d \pm \lambda_t^d) \tag{2}$$

where π_t^d = profit without SLM practices in year t;

Y_t^d = crop yield without SLM practices in year t;

Z_t^d = cost of production of one unit of Y_t^d; and

λ_t^d = off-site costs/benefits without SLM practices per unit produced in year t.

The social NPV (NPV^S) of adopting SLM practices is therefore given by:

$$NPV^s = \sum_{t=0}^{T} \rho^t (\pi_t^c - \pi_t^d) \tag{3}$$

where T = the farmers' planning horizon; and

$\rho^t = \left(\frac{1}{1+r}\right)^t$ = the farmers' discount factor, where r is the farmers' private discount rate.

Farmers will find it profitable to adopt SLM practices if NPV>0. However, a given farmer's decision to adopt SLM practices typically does not take into account the off-site costs and benefits that result from adoption or non-adoption of SLM practices, nor does the decision usually involve consideration of risk, credit constraints, and the size and irreversibility of the investment. The literature on these issues also establishes that a positive NPV may be far from sufficient to induce investment (e.g. Pender, 1996; Dixit and Pindyck, 1994; Fafchamps and Pender, 1997).

Following its definition, the IRR is given by:

$$NPV = \sum_{t=0}^{T} \left(\frac{1}{1+IRR} \right)^{t} (\pi_t^c - \pi_t^d) = 0 \tag{4}$$

The greater the IRR, the higher the rate of returns to investment.

The first step to computing equations (1) through (3) is to determine how crop yields (Y_t^c and Y_t^d) are affected by the SLM practices of soil fertility management, agroforestry, and SWC structures. Ideally, we need data from an experiment that includes all three SLM types and is conducted over many years, and thus captures the long-term biophysical changes and corresponding crop yield changes. To the best of our knowledge, no such experiment has been conducted in SSA or other countries with biophysical characteristics similar to those of Kenya. However, three sets of long-term and short-term experiments conducted in Kenya have separately investigated the response of crop yield to (i) organic and inorganic fertilizers and crop residue management, (ii) SWC structures, and (iii) agroforestry. The latter experiment examined the use of Calliandra hedgerows and Napier grass[5][6], which were selected because: (i) the catchment is very hilly and farmers often use these species for stabilization of *fanya juu* terraces; (ii) the farmers typically work small pieces of land and practice zero grazing, which means that the stabilizing material is fed to the animals and the manure is plowed back into the land, yielding double benefits; (iii) both species grow quickly, which is a crucial attribute when selecting plants for agroforestry practices; and (iv) Calliandra is a very nutritious feed for dairy cows, with 3 kg of on-farm-produced Calliandra replacing 1 kg of purchased dairy cow concentrate (Lenné and Thomas, 2005).

We therefore use the results of the above three sets of experiments to establish the relationship between crop yield and the three SLM practices studied herein. To simplify the modeling approach, we assume that crop yield is affected by soil moisture, soil quality (i.e. chemical and biophysical characteristics such as soil nutrients and bulk density), and topsoil depth. In low external input agriculture, such as that found in the study area, agronomists use topsoil depth to determine SOM and soil fertility in general (Koning and Smaling, 2005; Mantel and van Engelen, 2000; Nkonya, 1999). Following Prasad, et al. (2006) and Swan et al. (1987), the theoretical model of the determinants of crop yield can be summarized as follows:

$$\text{Crop yield}[Y] = f(\text{soil moisture, soil quality, topsoil depth}, \varepsilon_t) \tag{5}$$

where ε_t is a random error.

Topsoil depth (x) may not be a good indicator of soil quality, since two soils of the same topsoil depth may have quite different SOM levels. Hence, we introduce the soil quality term to account for such possibility. All three of the studied SLM practices affect soil quality and topsoil depth. There are many attributes of soil quality that are not easy to model, and even when land management and biophysical conditions are held constant these attributes will change over time under continuous cultivation. For example, in the long-term Kabete soil fertility trial, crop yield under continuous cultivation decreases because the SOM declines over time even in treatment plots receiving the highest rates of organic and inorganic fertilizer (Nandwa and Bekunda, 1998).[7] This implies that inorganic and organic fertilizers cannot replenish some nutrients required for increasing or maintaining crop productivity. Hence, holding

5 The other leguminous plants used in the previous SSA-based experiments include Leucaena spp, Gliricidia spp, Senna spp, Crotolaria spp, etc. (Samba, et al., 2002).

6 More details of these experiments are given below in the data section.

7 In the Kabete experiment, crop residues were chopped and incorporated into the treatment plots that received crop residues. In addition to depleting SOM, continuous cultivation even with the addition of adequate N, P, and K inorganic fertilizers could lead to depletion of other nutrients and degradation of the biological and physical properties of the soil.

land management and most biophysical conditions constant,[8] we can assume that the SOM will be strongly correlated with the number of years of continuous cultivation. Since SOM data were not available, we used the number of years of continuous cultivation as one of the indicators of soil quality in the present study. This is based on the findings of Nandwa and Bekunda (1998), Ssali (2002), and other studies showing that SOM decreases over time in continuously cultivated plots. We also used soil depth to represent soil quality (despite the above-noted drawbacks) because it is common to use soil depth for modeling the impact of land degradation on crop yield in many empirical studies in Africa (e.g. see Lal, 1995; Sparovek and Schnug, 2001).

We also used rainfall as an explanatory variable, since rainfall is a major determinant of crop production in rainfed agriculture (Prasad, et al., 2006). The need to control for rainfall is also justified by the fact that the previous soil fertility experiments in Kenya did not control for rainfall changes (e.g. by using irrigation). Hence crop yield was also determined by rainfall.

For treatments that controlled soil erosion by using SWC structures, Calliandra hedgerows and Napier grass, the amount of anthropogenic soil erosion is assumed to be zero ($x_t = 0$). Hence, the empirical model representing the impact of soil quality on crop yield with SLM practices over years is:

$$Y_t^c = \text{f(rainfall, number of years of continuous cultivation , } \varepsilon_t\text{)}. \tag{6}$$

The impact of rainfall on crop yield is likely to be positive exponential, since the crop yield response to rainfall will be very strong under moisture stress conditions but will taper off as moisture stress decreases, eventually becoming zero when soil moisture reaches a certain threshold.

Preliminary results of the Kenyan long-term soil fertility trial showed that the maize crop yield declined exponentially over years .[9] Hence equation (6) is explicitly specified in the following model (which shows the expected signs):

$$Y_t^c = e^{\beta_{0c} - \beta_{1c} t + \beta_{2c} h + \varepsilon_t} \tag{7}$$

where h = annual rainfall in mm, $\beta_{0c,}$ $\beta_{1c,}$ and β_{2c} are coefficients of the associated variables, and t = number of years of continuous cultivation. The other variables are as defined previously.

Likewise, exploratory analysis of the soil erosion experimental data in Kenya also showed a negative exponential relationship between soil erosion and crop yield. Hence, the without-SLM practices model (Y_t^d), with expected signs is:

$$Y_t^d = e^{\beta_{0d} - \beta_{1d} t + \beta_{2d} h - \beta_{3d} x_t + \varepsilon_{td}} \tag{8}$$

where x_t is the cumulative soil depth loss in cm, and ε_{td} is the error term. The other variables are as defined previously and, $\beta_{0d,}$ $\beta_{1d,}$ and β_{2d} are the coefficients of the associated variables,

Under equation (8), we assume that the farmer does not apply any form of fertilizer, does not incorporate crop residues, and does not control soil erosion.

Since the maize yield panel data are likely to be serially correlated, we test the with- and without-SLM models for first order autocorrelation [AR(1)]; because we are using panel data with each replication forming a unique serial data, we test for serial correlation of each replication. The Durbin-Watson test statistic for the without-SLM case ranges from 1.67 to 2.43, which is in the region indicating no serial correlation. However, the Durbin-Watson statistic for the with-SLM model ranges from 0.31 to 1.65, indicating the presence of within-panel serial correlation. Heteroscedasticity across panels is also a problem in the data. To address the potential issues of serial correlation and heteroscedasticity, we use the feasible generalized least squares (FGLS) model, which addresses both problems (Greene, 2003) .

8 Except for rainfall, which is controlled for in equations (5), and (6).
9 More details on this may be found in the data section.

Soil erosion is usually reported as an annual amount of soil that leaves the farm or plot per unit area (tons/ha/year). Hence we need to establish the relationship between amount of soil lost per unit area per year and the corresponding loss of depth of topsoil. This relationship, established in Kenya by Mantel and van Engelen (2000), is as follows:

$$x = \left(\frac{E}{10^4} * \frac{T}{B} \right) * 100 \tag{9}$$

where x = topsoil loss (cm);

E = soil erosion risk in kg $ha^{-1}yr^{-1}$;

T = the number of years in the planning horizon (in this study we seek to understand the loss of topsoil depth over 50 years); and

B = bulk density of topsoil in kg m^{-3}.

Since agroforestry is one of the technologies used to control soil erosion and improve soil quality, it is implicitly incorporated into equation (7) and (8). Additional details of how we treated agroforestry are given in the next section.

Data

The data section describes how we compute the costs and benefits for farms with- and without SLM practices. We use data from the Kinale/Kikuyu watershed, located in the central provinces of Kenya. This watershed is one of the sources of potable water for the city of Nairobi, which is the capital city of Kenya. To capture the long-term response of crop yield to SLM practices, this study mainly uses data from maize experiments conducted at the Kabete and Embu research stations, both of which are located in high agricultural potential areas of the Kinale/Kikuyu watershed, Kenya. The Kabete long-term soil fertility trial, which has been running since 1976, examines the combined use of farmyard manure (0, 5, and 10 tons/ha), nitrogen and phosphorus (0, 90, and 180 kgNP/ha each), and crop residue management (incorporation or no incorporation). All combinations are tested for a total of 18 treatments, each of which are planted in four replications per year. This experiment is the longest running soil fertility trial in Kenya, and captures the long-term impact of soil fertility management practices on crop yield. Thus, data from this trial are used as benchmark for the SLM practices considered in this study. To analyze the with- and without-SLM scenarios, we use two specific treatments that reflect the recommended fertilizer rates in the study area, namely: (i) application of 90 kgN/ha plus 30 kgP/ha of inorganic fertilizers, 5 tons/ha of farmyard manure, and incorporation of crop residues; and (ii) no application inorganic fertilizer, organic fertilizer, or crop residue (control treatment reflecting the case without soil fertility management practice, leading to soil nutrient depletion).

Data from two experiments conducted at the Embu agricultural research station were used to quantify the impact of SWC structures and agroforestry practices on maize. The first Embu experiment sought to determine the impact of multipurpose shrubs (Calliandra and Napier grass strips, alone or in combination) on crop yield over a five-year (1993-1997) experimental period (Okoba and O'Neill, 1998). This is relatively a short period that should not be taken as reflecting the long-term impacts of agroforestry practices. To address this problem, we use the Kabete fertility trial to compute the long-term crop yield trends, and then incorporate the impacts of agroforestry (Calliandra and Napier grass) using data from the Embu agroforestry experiment. Since the agroecological conditions are similar at Kabete and Embu, the impacts of agroforestry in both sites should be comparable if all other factors are held constant. Studies by ICRAF (2005) in western Kenya have shown that agroforestry practices have the potential to increase crop yield by two to four times compared to the yield on plots receiving no organic/inorganic fertilizers or agroforestry. However, the impact of agroforestry practices on crop yield is likely to be much smaller on plots with a high SOM or those receiving organic and/or inorganic fertilizers. Hence, we herein assume that the agroforestry practices have no significant impact on crop yield in the first few years of the with-SLM scenario. We can make this assumption based on the Embu experiment, which showed that Calliandra and Napier grass did not have a significant impact on maize yield in the first five years (Okoba and O'Neill, 1998). Then, beginning in the sixth year, we introduce a coefficient that adds a certain percent of crop yield to reflect the potential of agroforestry to help maintain high crop yield on continuously cultivated plots. However, we use the results from the Kabete experiment as the benchmark, since the Embu agroforestry trial was conducted for only a few years and does not give the long-term impact of agroforestry on maize yield.

If we let Y_t^a = crop yield with SLM practices (including agroforestry, inorganic and organic fertilizers, incorporation of crop residues, and SWC structures) in year t, then

$\hat{Y}_t^c$ = estimated crop yield with SLM practices in year t (number of years of continuous cultivation). Equation (7) then becomes:

$$Y_t^a = \hat{Y}_t^c \alpha_t \tag{10}$$

where α_t is the rate of crop yield increase due to agroforestry practices in time t. As discussed above, α_t = 0 during the first five years.

The objective of the second Embu experiment was to determine the impact of soil erosion on maize grain yield. The experiment was conducted for five years (1993-1997)[10] on plots with slopes ranging from 15% to 20%, which reflects the average slope of the Kinale/Kikuyu watershed.[11] Hence, for our without-SLM scenario, we herein use data from the Kabete experiment but reduce the estimated crop yield by a percentage reflecting the impact of soil erosion on crop yield.[12] The results from the Kabete experiment show that maize yield decline at an average of 5% per centimeter of soil lost.[13] This is consistent with the range of estimates provided by Weibe (2003), who performed an exhaustive review of experimental studies of soil erosion impacts and found that most studies report yield reductions of 0.01 – 0.04% per ton/ha of soil lost, with generally lower values in more temperate regions. Assuming that soil has a bulk density of 1.3 tons/m^3, one cm of soil is equal to 130 tons/ha, which converts to 1.3 – 5.2% yield loss per cm of soil lost.

In addition to increasing crop yield, agroforestry practices have other benefits that affect the profitability of SLM practices. These benefits are considered in computing the benefits and costs in equation (1) as follows:

Calliandra and Napier grass are used to stabilize and/or replace SWC structures in moderately sloping areas. Hence, planting of shrubs and grass on SWC structures reduces their maintenance costs.[14] Discussions with soil scientists conducting agroforestry and soil erosion in Kenya revealed that planting Calliandra hedgerows and Napier grass strips could reduce labor for maintaining SWC structures by 75%. Accordingly, we reduced the labor for maintaining SWC structures by 75% for the with-SLM practice scenario.

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10 Since Embu is located in the high agricultural potential area, as are most of the watersheds, these soil erosion trial data reflect the biophysical environment of the selected watersheds better than those used by Pagiola (1996), which came from Machakos (a much drier area with different soil characteristics).

11 The Kenya Agriculture Act (Cap 318) of 1980 prohibits agricultural activities on land with a slope exceeding 35%. The law also requires that farmers must have SWC structures on crop plots with slopes of 12% to 35% (Government of Kenya, 1986).

12 The experiment at Kabete is established on plots with very small slopes that do not require any form of SWC structure. Hence, it may be taken as reflecting the yield of crops planted on steep slopes, but with SWC structures that effectively control soil erosion.

13 The results from a similar experiment conducted at Machakos, Kenya, showed that one cm loss of soil topsoil depth led to a loss of 0.13 tons of maize grain yield/ha (Pagiola, 1996), which was equivalent to about 7% of the yield with zero soil loss. The rate of crop yield loss due to erosion is lower in more fertile soils such as volcanic soils (andosols and nitisols) that are rich in nutrients (Mantel and van Engelen, 2000).

14 Agroforestry practices also increase soil nutrient inputs, enhance internal flows, decrease nutrient losses, and provide other environmental benefits (Sanchez et al., 1997).

Calliandra biomass is harvested and used to prepare dairy meal and Napier biomass is used as fodder. The prices of the dairy meal and Napier fodder are reported in Table 1.

Table 1. Prices of outputs with and without Sustainable Land Management practices

Output	Price (KES/ton)[1]
Maize grain: Private price[2]	10,750
Social price[2]	10,556
Calliandra biomass (dairy meal)[3]	17,000
Napier biomass[2]	833
Maize biomass (which farmers without SLM feed to livestock)	833
Carbon stock[2] (accumulated due to control of soil erosion) ($3.5/ton)	255.5

Source: Authors' calculations using primary data
[1] KES = Kenyan Shillings
[2] Private price is the price that individual farmers receive without taking into account transfers or costs. For example, if the government fixes a flow price (P_f), which is above the market price (P_m), the government will pay the difference (P_m) – (P_f) in a transfer. In this example, the private price = P_f and the social price = P_m.
[3] Carbon accumulation due to SWC and soil fertility management is 0.2 to 0.7 tons C/ha/yr (Vagen et al., 2005, Gachene, 1997), which is an average of 0.5 tons C/ha/yr. Higher carbon sequestration rates are realized for agroforestry practices planted without crops. Woomer et al. (1998) estimated that agroforestry trees could accumulate an average of 3.3 tons of carbon per hectare per year.
Note: Prices of biomass are not regulated, hence private prices = social prices.

The aboveground Calliandra and Napier biomass has the potential to absorb carbon dioxide from the atmosphere (Unruh et al., 1993; Woomer et al., 1998; Sanchez et al., 1997) while the underground biomass (roots and stems) store carbon (Batjes, 2004). To account for these global benefits, we impute a value equivalent to the benefits of sequestration offered by the agroforestry practices. As mentioned earlier, studies of carbon sequestration indicate a value of US$ 3.5 per ton of carbon biomass stored above- or belowground (Table 1). The raw data from the Embu agroforestry experiment show that the Calliandra and Napier grass biomass left on the ground after harvesting is about equal to the harvested biomass, and that Calliandra and Napier grass continue to grow after their biomass is harvested. During the growing time, which lasts approximately four to six months, these plants provide the environmental services of storing carbon and absorbing carbon dioxide. The non-harvested carbon (roots and other stem tissues) continue providing such services throughout the year.

When agroforestry trees, shrubs and grass are planted in crop plots, they may compete with crops for space, light, nutrients and moisture (Ibid; Unruh et al., 1993). The Embu trial showed that Calliandra and Napier did not cause statistically significant changes in maize grain yield for the first five years. This is probably due to the rich SOM at the experimental site, which blunted the impact of the additional nitrogen fixation and organic matter represented by the Calliandra and Napier in the first few years.15 Another possible explanation could be low competition for nutrients, water and light during the first few years in an agroforestry system, and limited competition for water and nutrients due to the high rainfall and good soils of the area. Competition for nutrients was further minimized since Calliandra releases nutrients from decomposition of leaves/roots, and fixes atmospheric nitrogen. Furthermore, the

15 The maize yield in the Kabete long-term soil fertility trial also showed poor response to fertilizers in the first few years, probably for the same reason (high initial SOM in virgin plots). The agroforestry trees and shrubs are likely to show stronger impacts on the yield of crops grown on land with low SOM and soil nutrients (Sanchez et al., 1997; Woomer et al., 1998). Hence, we expect that maize yield in the Embu agroforestry trial will show a greater response to the agroforestry treatment in subsequent years.

researchers added inorganic fertilizer, and annual harvesting of the aboveground Calliandra biomass reduced the competition for light. In terms of space lost, there were five Calliandra hedgerows or Napier grass strips per hectare. Each row occupied a space of 0.6 m by 100 m long. Hence, the space taken up by Calliandra hedgerows and Napier grass was about 3% of one hectare of maize; the unit area remained one hectare, but the space planted to maize was reduced by 3% and the yield (kg/ha) of maize was reduced in proportion to the area taken away by the trees. To account for the area lost to planting Calliandra hedgerows and Napier grass strips in our analysis, we reduce the maize grain yield by 3%. The costs of establishing the agroforestry practices and other costs are considered and reported in Table 2.

Table 2. Production costs with and without Sustainable Land Management (SLM)

Particulars	Material input			Labor input		Total
	Quantity	Units	Price	Days/ha	Pay/day	
			KES		KES	KES
Land preparation				35	100	3500
Maize seed & labor for seeding	32	kg	130	20	100	6160
Napier grass planting material & labor for planting*	5000	cuttings	2	2	100	10200
Calliandra seedlings & labor for planting*	6665	seedlings	5	2	100	33525
Construction of SWC structures (*fanya juu*)*				32	100	3200
Maintenance of SWC structures**				22	100	2200
Fertilizer: Nitrogen & labor for application	60	kg	76.47	0.5	100	4638.24
Phosphorus & labor for application	30	kg	57.14	0.5	100	1764.29
Manure transportation & application	5	Tons	142.86	20	100	2714.29
Weeding: x 2				45	100	4500
Harvest maize grain				15	100	1500
Harvest & transport maize biomass				5	100	500
Total variable labor input with SLM				162		
Total variable labor input without SLM				120		
Total one-time initial costs with SLM					46925	
Initial cost as % of total cost (initial & variable cost) of SLM					64%	
Total variable costs (with SLM)						26976.81
Total variable costs (without SLM)						15035

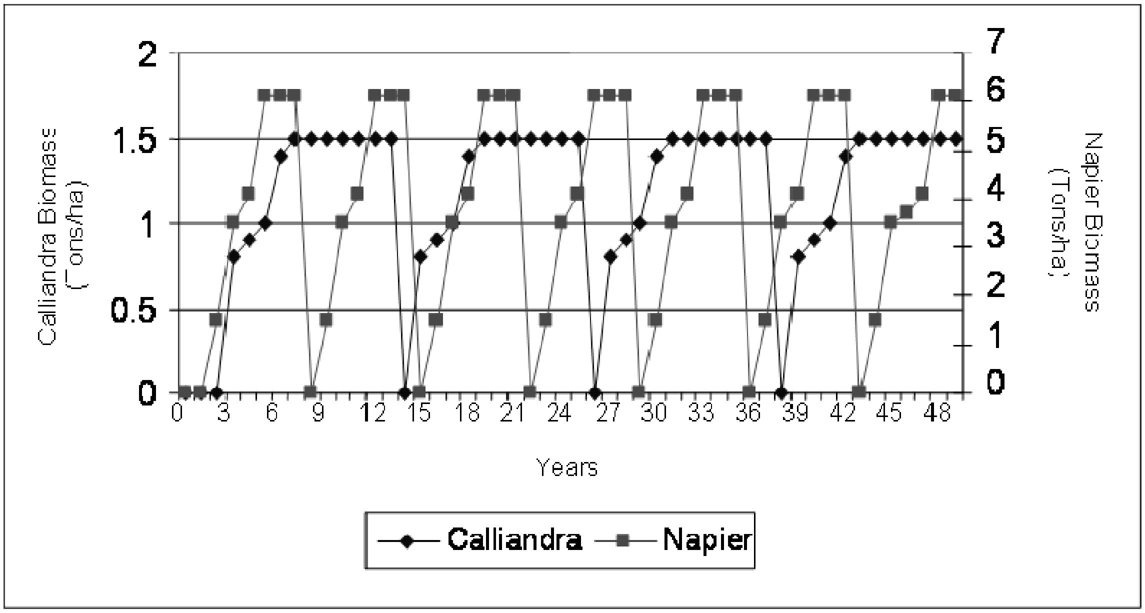
Source: Authors' calculations using primary data

* Cost incurred in the first year only.

** When farmers reinforce their SWC structures by planting Calliandra and Napier grass, their maintenance costs drop by 75%.

To allow Calliandra and Napier to grow, their biomass was not harvested in the first year after planting. Their biomass increased at first, and leveled off in the fourth to fifth year (see Figure 1).

Figure 1. Calliandra and Napier biomass over the 50-year planning horizon



Source: Authors' calculations using primary data

After estimating Y_t^c and Y_t^d and using the experimental data to examine how they are influenced by the presence or absence of SLM practices, we estimate equations (1) to (3) using crop production budgets estimated using different levels of input use reflecting the practices in the studied areas. Table 2 shows the maize production costs with and without adoption of SLM.

Since we are analyzing social CBA, we account for the input and output price distortions. Kenya imports all of its inorganic fertilizer, but fertilizer is classified by the Kenyan Revenue Authority as an essential import and therefore does not have an import tax. Kenya produces most of its maize seed locally, and the government does not regulate maize seed prices. Thus, fertilizer and seeds should have negligible price distortions. However, the government does participate in the maize market, contributing to market distortions. For example, the National Cereal and Produce Board (NCPB), which is a government institution, bought 0.18 million tons of grain in the 2005/06 season, representing about 6.7% of the maize demand in Kenya. In this case, the NCPB bought maize grain at KES 13.33/kg when the maize market price was KES 10.56/kg. However, the NCPB price was paid for only 6.7% of the maize consumed in Kenya. Hence the weighted average price of maize after government intervention was KES 10.75 (13.33*0.067+10.56*0.933) per kg, suggesting that the estimated price distortion was around KES 0.19/kg, or KES 190/ton. In contrast, the prices of Calliandra, crop residues, and Napier grass are not regulated or taxed, and thus have no distortions.

Kenya does not import a large volume of maize under normal circumstances. For example, only a net of about 10,000 tons of maize was imported in 2003 (CBS, 2004) at a tariff of 50% of Cost Insurance and Freight. Since only a small volume of maize is imported into the country, we do not use an import tariff distortion in our analysis.

Estimation of the off-site costs of land degradation is complicated by a general lack of data. As discussed earlier, land degradation has many potential local, national and global off-site effects. Our study focuses on the land management practice-related off-site effects that affect soil erosion and carbon stock on cropped farmland. The major off-site effects of soil erosion include sedimentation of surface water bodies such as lakes, ponds, reservoirs and waterways. Siltation increases the costs of water facility maintenance and replacement, and complicates the purification and treatment of potable water (Moore and McCarl, 1987). Soil erosion also affects soil organic carbon and aboveground vegetation. However, the contribution of agriculture to anthropogenic soil erosion is not fully understood at this time, and other anthropogenic activities, such as road construction, could cause significant soil erosion (Pagiola, 1999).[16] Furthermore, soil eroded from agricultural land is often deposited elsewhere within the farm or on neighboring farms, while soil that reaches waterways may be deposited on the streambed. Hence, the share of eroded soil reaching surface water bodies and reservoirs is always very small. For example, in large watersheds the sediment delivery ratio (the sediment that exits the watershed as a share of gross erosion) is only 0.05 (Stocking, 1996).

In this study we estimate that the cost of potable water production from Sasumua Water Treatment is KES 14.77 million, of which KES 9.91 million is costs due to soil erosion (Table 3). [17]The Sasumua Water Treatment Plant which supplies around 20% of the potable water in Nairobi city. Staff members at the Sasumua Water Treatment Plant estimated that the cost of water treatment and purification during the dry season reflects the costs of water treatment and purification when all farmers effectively control soil erosion (i.e. when water production is not affected significantly by soil erosion and other agricultural activities that pollute water). Thus, we use the cost of water treatment and purification during the rainy season as reflecting the scenario in which land degradation is present. Untreated, unpurified water is characterized by increased turbidity (due to solids such as soil, crop residues, animal droppings, etc.), bacterial count, pH, coloration, and agrochemical loading. Water that has been compromised by siltation/pollution must be treated and purified using above-average amounts of alum (aluminum sulfate, a coagulant used to purify water) and chlorine (used to disinfect the water) (Table 3). This use of elevated levels of alum lead to a sludge buildup that requires frequent backwashing, a process involving a large amount of water that must be disposed of after backwashing. Furthermore, silt built up in the water reservoirs and intakes must be dredged. Data obtained from the Sasumua Water Treatment Plant show that the use of alum, chlorine, backwashing and removal of siltation has increased water production cost by KES 9,904,041 per year.

Table 3. Increases in the cost of water treatment and purification due to land degradation

Type of treatment/purification	Treatment	Cost without SLM (million KES per 7 months)	With SLM (million KES per 5 months)	Incremental cost (million KES/year)
Purification of water	Alum	8.30	1.78	5.81
Treatment of water	Chlorine	0.39	0.16	0.17
Sludge removal	Flush with water	0.53	0.11	0.43
Cleaning of siltation	Dredge sediments			3.50
Total incremental cost				**9.91**

Source: Authors' calculations using primary data
Notes: The incremental costs are computed by multiplying the additional costs of water treatment during the wet season times the number of wet season months, rather than taking the difference of costs with and without SLM.

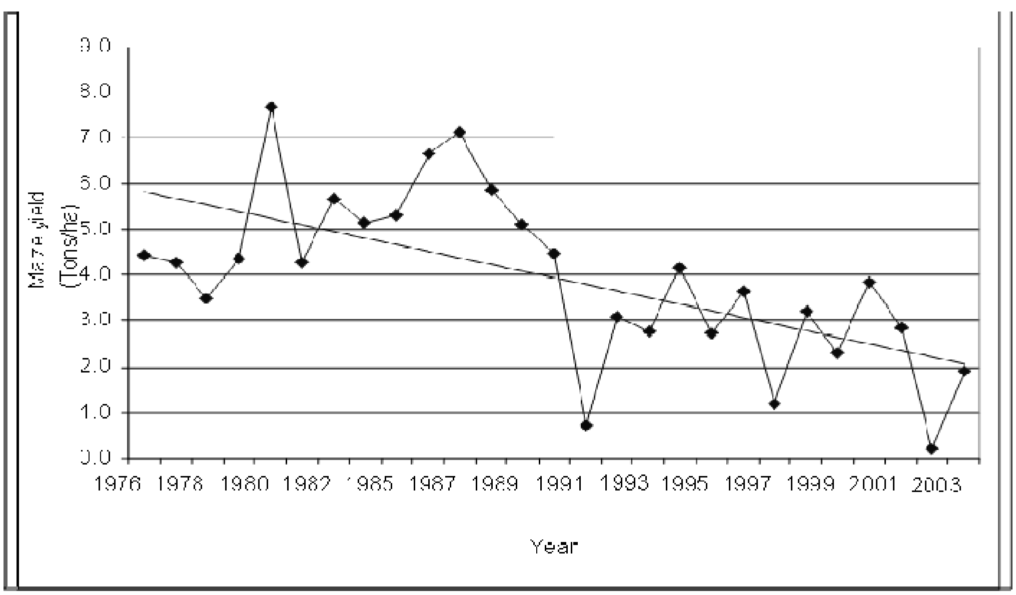
16 Ecological erosion can also contribute significantly to soil erosion. It is estimated that ecological erosion of undisturbed forest is about 20 – 30 t/km2/year (Shepherd et al., 2000).

17 Details of how this was computed are given below.

4. RESULTS

Figure 2 shows the actual maize yield of the control treatment plots (no incorporation of fertilizer, manure or crop residues) in the Kabete soil fertility trial. The declining yield reflects the impact of soil fertility mining and the declining crop yield that is commonly seen among the majority of SSA farmers who apply limited external inputs. Similarly, Figure 3 shows the actual maize yield on plots that received 60 kg of nitrogen, 30 kg of phosphorus, and 5 tons of manure per ha annually, along with incorporation of crop residues. The maize yield also declines in these plots, but at a slower rate than in the case of the control treatment. These data were used to simulate the yield of maize over a longer period of time. Figure 4 shows the simulated maize yield, which declines for both the with- and without-fertilizer, -manure and -crop residue treatments. Figure 4 also shows the regression results of the crop yield model. The rate of decline for the without-fertilizer, -manure and -crop residue treatment is much faster than that for plots with SLM practices, and the intercept is also lower without SLM. The predicted maize yield for the two scenarios (Figure 4) shows that over a 50-year period, the maize yield for plots grown with fertilizer, manure and crop residues is 5.5 tons/ha in the first year, but declines thereafter at a rate of 2.5% annually, which is equivalent to an approximate reduction of 135 kg of grain per year. However, the rate of decline decays over time as yield decreases. For example, the rate of decline of maize yield for the SLM scenario in the first 10 years of the 50-year period considered herein was X, which is equivalent to Y kg/yr, whereas in the last 10 years of the study period, the decline rate was 2.4%, which is equivalent to 60 kg/year.[18] The corresponding rate of maize yield decline for the without-fertilizer and -crop residue scenario is 3.8% per year. In the 50th year, the maize yield of plots grown with fertilizer, manure and crop residue is estimated to decline to about 1.5 tons/ha, which is comparable to the actual yield obtained by farmers, as reported by de Groote et al. (2005). The maize yield for plots grown without fertilizer, manure, or crop residue is projected to decline to about 0.7 tons/ha in the 50th year. This crop yield trend shows the long-term impact of land degradation resulting from continuous cultivation, which is a common problem in areas with high population density.

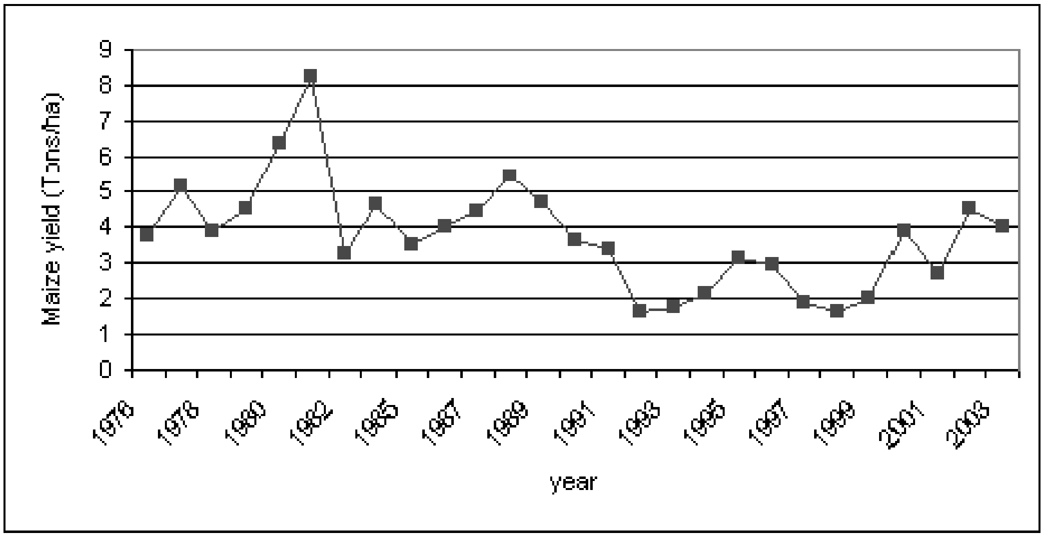
Figure 2. Actual experimental maize yield from plots grown without fertilizer, manure or crop residues



Source: Authors' calculations using primary data

18 The average yield of maize in the SLM scenario in the last 10 of the 50 years of simulation is 2.5 tons/ha.

Figure 3. Maize yield trend from plots grown with SLM practices (addition of fertilizer, manure and crop residues)



Source: Authors' calculations using primary data

Economic Viability of SLM Practices

Next, we evaluate the impacts of the SLM practices considered in this study (60 kg of nitrogen, 30 kg of phosphorus, 5 tons of manure, incorporation of crop residues and SWC practices reinforced with Calliandra and Napier grass) on maize yield. As shown in Table 2, implementation of all these SWC practices involves high initial investments that may not be tenable among resource-poor farmers. If a farmer is willing to make such an investment, he/she might choose to implement the entire initial investment in the first year by constructing SWC structures and stabilizing them with Calliandra and Napier grass. Alternatively, he/she might stagger the initial investment over a period of time, making each payment more tenable. Investigation of the two options (see below) shows that staggering the initial investment is more efficient compared to simultaneous investment in all technologies during the first year.

If a farmer chooses to adopt all of the SLM practices in the first year, he/she will realize a total 50-year private NPV of KES 152.31/ha and a total social NPV of KES 176.05/ha. The initial fixed costs account for 64% of the total (fixed and variable) costs of the SLM practices in the first year (Table 3). Almost 50% of the initial cost may be ascribed to the Calliandra seeds, suggesting that this legume is likely to be one of the most important barriers to adoption if its planting material is not made cheaper and more easily available. The high initial cost underscores the barrier to adoption of SLM practices, which may be difficult for poor households to address.

Figure 4. Regression equation lines showing maize yield with and without SLM based on the Kabete fertility experiment

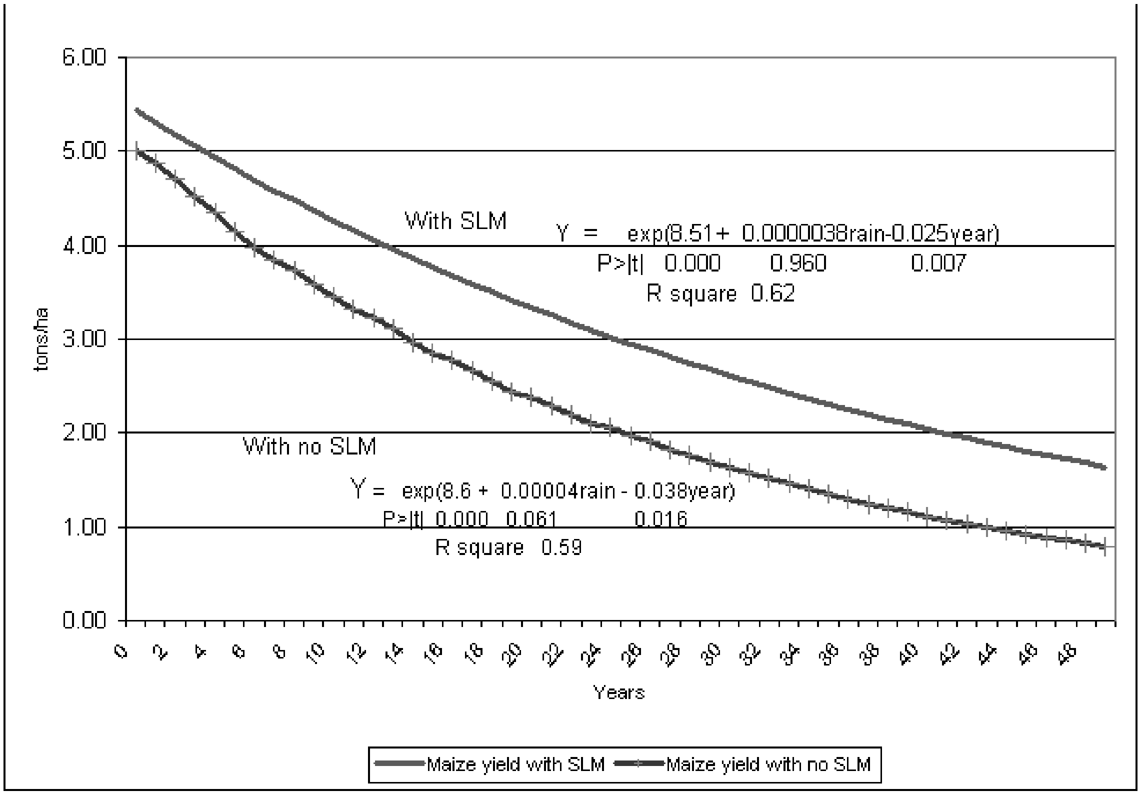


Table 4. Fifty-year social and private NPV, IRR and off-site benefits and costs

	Private	Social
Total NPV ('000 KES/ha)	152.31	176.05
Average NPV/year ('000 KES/ha)	3.05	3.53
Value of carbon sequestered as % of NPV		10.00
Cost of water treatment and purification as % of NPV		4.79
IRR (%)	30.70	39.00

Source: Authors' calculations using primary data
Notes: (i) The total water treatment costs were divided by the total area cultivated in the catchment.
(ii) Carbon sequestered includes carbon saved in the crop plot due to control of soil erosion (0.5 tons/ha/year) and the below- and aboveground carbon stores of the Calliandra and Napier plants.

In contrast, staggering the investment over four years significantly lowers the cost from a one-time investment of around KES 50,000/ha for the private NPV to a total of only KES 15,430/ha. The IRR rates obtained in this study for the staggered investment strategy (39% for the social NPV and 30.7% the private NPV) are comparable to those obtained in other SWC studies conducted in Central America and the Caribbean, where the SWC IRR ranged from 11% to 84% (Lutz et al., 1994). These social NPV and IRR results suggest that if all other aspects are held constant, adoption of SLM practices is profitable. The private NPV and IRR also show that this is true even when we ignore the off-site costs and benefits.

The social NPV is higher than the private NPV due to our valuation of the carbon stock resulting from biomass production of Calliandra and Napier grass, as well as our inclusion of the costs of the off-site negative impacts of soil erosion for the without-SLM scenario (Table 4). The global benefits resulting from carbon sequestration account for about 10% of the total NPV/ha, and the costs due to water treatment and purification comprise about 5% of the social NPV. The contribution of off-site costs and benefits is significant, indicating that farmers may have to pay large costs to address negative off-site effects such as downstream siltation. However, farmers and other land users receive no compensation for the environmental services they provide to the public. For example, Payment for Environmental Services (PES) in Kenya is still limited to services related to game parks, whereas most environmental services offered by farmers do not receive compensation. This may engender common attitude of disregard for the externalities of farm production and sub-optimal land use.

Sensitivity Analysis

Next we examine the robustness of our results by analyzing the sensitivity of the NPV and IRR to changes in the input and output prices and the presence or absence of a dairy sector. We use the staggered SLM investment results because they showed higher profitability than the one-time investment, which the smallholder farmers might not be able to afford. As shown in Table 5, we first test a pessimistic scenario in which the price of maize falls by 50% from KES 10,750 to KES 5,375 per ton. This leads to a 25% drop in the social 50-year total NPV from KES 176,050 to 131,990 per hectare for farmers with SLM practices (Table 5). The private NPV drops by 28% while the private and social IRRs drop only slightly. The drop of NPV for the farmers who practice SLM is cushioned by the revenue from the Calliandra and Napier biomass, suggesting that adoption of agroforestry practices involving multi-purpose trees and shrubs reduces risk exposure. When we double the fertilizer price, the social and private NPVs decrease to levels comparable to those experienced after the 50% fall in maize price. If we apply both scenarios (fertilizer prices double and maize price falls by 50%), the total 50-year social NPV for adopting SLM practices falls by about 50% but the corresponding IRR for adopting SLM practices is greater than the discounted rate of 10% (Table 5). These results suggest that adoption of SLM practices is profitable over a wide range of output and input prices.

We then investigate the feasibility of adopting SLM practices in an area with no economic use for the Calliandra and Napier biomass (i.e. with weak or no dairy production activities). Table 5 shows that if the Calliandra and Napier grass biomass is not used for dairy production, the total 50-year social and private NPVs drop dramatically to KES 39,190 and KES 7,790 per hectare, respectively. The corresponding IRR is 10% for the social scenario and about 1.9% for the private scenario (Table 5). These results demonstrate that the profitability of the SLM practices depends heavily on the presence of a dairy sector (or other synergistic benefits of the SLM practices). Without dairy production, the NPV and IRR for adopting SLM practices are also very sensitive to changes in input and output prices. A 50% decrease in maize price leads to negative 50-year total NPVs for both the private and social scenarios. In general, changes of all input prices leads to negative social and private NPVs in the without-dairy sector scenario. These results suggest that in areas lacking in dairy production or other synergistic enterprises, SLM practices have low returns and are risky, and are hence unlikely to be adopted. In the absence of PES or other incentives, farmers in areas with weak or no dairy production are not likely to adopt the SLM practices analyzed in this research, and will therefore not prevent the negative off-site effects of land degradation. This is a major concern that needs to be addressed through promoting SLM practices in areas with weak or no dairy production.

Table 5. Sensitivity analysis of NPV and IRR under different pricing conditions, with and without a dairy sector

Change	Social NPV (KES '000)	Private NPV (KES '000)	Social IRR (%)	Private IRR (%)
Baseline (no change)	176.05	152.31	39.00	30.70
Maize price halved	131.99	109.03	42.0	29.5
Maize price halved and fertilizer price doubled	90.29	67.33	25.0	15.8
Fertilizer price increased by 50%	134.55	110.61	27.0	19.7
No dairy	39.19	7.79	10.0	1.9
No dairy, maize price halved	-4.86	-35.49	-	-
No dairy, fertilizer price doubled	-2.51	-33.91	-	-
No dairy, fertilizer price doubled, & maize price halved	-46.52	-77.19	-	-

5. CONCLUSIONS AND IMPLICATIONS

This study investigates the private and social returns to some Sustainable Land Management (SLM) practices with the objective of finding practices that will reduce the on- and off-site negative effects of land degradation. Our results show that farmers who do not use fertilizer or crop residue inputs experience approximately 4% maize yield loss annually, while those using fertilizer and crop residue inputs will still experience a crop yield loss of 2.5% annually, due to soil organic matter depletion from continuous cultivation. These results suggest that the use of fertilizer alone does effectively address declining agricultural productivity due to land degradation. This is consistent with the results of other studies showing that integrated soil fertility management, which combines fertilizer and organic soil fertility management practices, is more sustainable than the use of fertilizer alone (e.g. Bationo et al., 2007). Likewise, the use of organic soil fertility management practices alone is not sustainable due to the low content of phosphorus and other nutrients in organic matter (Ibid).

We further show that the use of Soil and Water Conservation (SWC) structures and their reinforcement with agroforestry practices are profitable when the agroforestry practices (e.g. Calliandra and Napier grass) are used as fodder for dairy cows. These results suggest that SLM practices have the potential to be adopted in areas with a strong dairy sector, thus addressing both the on-site and off-site negative impacts of land degradation. These results also suggest that SWC practices with multiple objectives are more likely to be adopted than those with a single objective.

One of the major concerns for the widespread adoption of SLM practices is that a high initial investment cost is required to establish SWC structures and reinforce them with multipurpose agroforestry shrubs and grass, yet most farmers have a limited capacity to invest. Our analysis suggests that the initial costs account for 64% of the total cost of maize production in the first year. If a farmer decides to adopt all the SLM practices in the first year, he/she will incur a loss of about Kenyan Shillings (KES) 50,000/ha, which was about a third of the household income in Kenya in 2005. This initial investment cost is certainly a barrier to adopting SWC structures and agroforestry, and likely explains their low adoption rate. One strategy that farmers may use to address this constraint is to stagger the initial investments over several years. However, even if the investments are staggered over a period of three to four years, the farmer will still incur initial losses of about KES 15,430/ha over the four-year investment period, suggesting that some farmers may not be able to adopt SLM practices even if they have the option of staggering the initial investment.

These results have important implications for addressing the off-site impacts of land degradation in sub-Saharan Africa. Investments in SLM practices in SSA have typically focused on subsidization of fertilizer, with little effort made to invest in agroforestry and other alternative soil fertility management practices (Anon., 2007). The results of the present study suggest that it will be necessary to increase the investment in agroforestry practices in order to help farmers to reduce the initial high costs of SLM investments. For example, establishment of commercial agroforestry nurseries could help reduce the largest initial cost of buying Calliandra and Napier plants or any other agroforestry tree/shrubs/grasses in the first year. Currently, the production and marketing systems for agroforestry planting materials in SSA are poorly developed (Russell and Franzel, 2004). It could be helpful to improve these systems as part of efforts to address land degradation; for example, improvements in agroforestry planting material production would be likely to reduce the high cost of Calliandra, increasing its adoption.

To reflect the biophysical and socio-economic diversity in the study area, we investigate the profitability of SLM practices in areas that are lacking in the dairy production sector. Our results show that in areas with weak or no dairy production, SLM practices are risky when agricultural prices change significantly. These results suggest the need to promote SLM practices that complement not only each other, but also other farm enterprises. It could be useful to develop a package of complementary technologies that together are more profitable and less risky in a given region. As discussed above, however, a package of technologies implies high initial fixed or variable costs. In the quest to promote a package of technologies, implementers should aim for stepwise adoption of the technology components

(Byerlee et al., 1986), and plan SWC structures involving agroforestry practices that have alternative uses (e.g. dairy fodder, firewood, etc.). Our study shows that promotion of agroforestry practices solely for the sake of controlling soil erosion and its off-site effects may not work. If it is not feasible to promote a mix of complementary enterprises, high value crops are likely to make SLM practices more profitable (Place et al., 2002). However, risk and access to market are likely to be of concern for high value crops. For example, it is risky to grow cut flowers in northern Kenya where there is low access to roads and airports. In areas where SLM practices are not profitable, promotion of alternative livelihoods will be necessary. For example, non-farm activities are likely to give farmers alternatives to land-degrading agricultural activities. A study in Uganda showed that farmers who had non-farm activities were more likely to allow their fields to lie fallow than those without (Nkonya et al., 2005).

Another approach that could increase the adoption of SLM practices is Payment for Environmental Services (PES). For PES to be sustainable it needs to be a win-win situation, i.e. it must increase the returns to SLM practices while helping downstream communities avoid or minimize the off-site effects of land degradation. For example, if the Sasumua Water Treatment Plant were to pay farmers to adopt soil and water conservation technologies, it could reduce its potable water production costs and help farmers realize profits from adoption of SLM practices. Future work will be required to fully explore the potential of PES to enhance adoption of SLM practices.

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